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OTTAWA
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SECTION FIVE

FLAVELLE MEDALIST'S ADDRESS

Parasitology and the Arctic

THOMAS W. M. CAMERON, F.R.S.C.

PARASITOLOGY is one of the oldest branches of medicine and of biology. Parasites were recognized in the earliest days of written history because the parasitic worms or helminths include some quite large forms and so were easily visible. Some escaped spontaneously from the body and from their elongated snake-like appearance became identified in the human mind with snakes and so with harmful results. In fact, there is every reason to believe that much of the human fear of snakes can be associated with confusion between them and the common Roundworm and the Guinea worm.

The latter is almost certainly none other than the Fiery Serpent of the Exodus. It is a string-like creature, several feet long, which usually lives coiled up among the tendons of the human ankle. It is found in the warm lands between West Africa and eastern India. When gravid, the female worm secretes a fluid just under the surface of the skin. This causes an intense burning sensation which is assuaged by bathing in cold water. This, in turn, causes a prolapse of the creature's uteri through her head region and a discharge of the numerous larvae into the water. (The larvae subsequently develop in various minute crustacea and return to man in the drinking water.)

The worm is removed by the natives of these lands by a technique well illustrated by Moses' model of his Fiery Serpent. The head of the now dead parasite is seized and tied round a sliver of bamboo and gradually, each day, a little traction having been exercised on the still elastic worm, the creature is extracted. As the process goes on, the worm is wound around the stick and often looped around the ankle for security. If the traction is so excessive that the worm breaks, the hind end retracts into the wound; a septic infection almost inevitably results; and the patient may lose his foot —if not his life.

The burning, fiery sensation provided by the gravid worm and the method of extraction, as well as the geographical distribution, help to identify this worm with Moses' serpent. It is still known as the Medina worm, after the district so close to Moses' dramatic lesson.

Ascaris lumbricoides—the common Roundworm of man—was also well known to the ancient Egyptians and Greeks. Its habit of not infrequently leaving the body spontaneously must have attracted their attention. Small pinworms also left the human body spontaneously, and tapeworm segments

did the same thing. All of these not only fostered the idea of spontaneous generation, but gave the worms a high importance in the causation of disease. In fact, together with a belief in the epidemic influence of gods and demons, they represent the foundations of medicine, and gave status to the priest-physician, who was at once both a psychiatrist and a parasitologist, as well as a practical psychologist.

The occurrence of certain species of snakes (such as the common, non-poisonous *Coluber aesculapius* [now known as *C. longissimus*]) in graveyards, the obvious pathology of the venomous kinds, the presence of snake-like creatures in the human body, and the fiery sting of the Guinea worm produced a set of circumstances which not only invested the snake with a reputation for wisdom above all other animals but also invested the god Hermes, as his badge of authority, with the caduceus, the same fiery serpent which Moses had shown to his people.

Hermes, the Greek messenger of the gods, later became the patron god of science, commerce, eloquence, arts, and of thieves. He was also the god of medicine and conducted souls to the underworld. The Greeks probably received their inspiration from the Egyptian god Thoth (who is identified in Greek mythology with *Hermes trimegistus*). Thoth was the founder of alchemy, and at least some of his functions were transferred from the deified Egyptian physician whom we know as Aesculapius, and who may well have utilized the extraction technique subsequently used by Moses during the Exodus.

In due course, Hermes was adopted by the Romans under the name of Mercury, and the worm became a formalized snake and was identified even as to species. *Coluber longissimus* is widely distributed over south Europe and is a vicious biter when freshly captured (although it quickly becomes tame and readily accepts small mammals offered it as food). It has a long hibernation period which commences about October and lasts until May, and this is another factor pointing to its association with the gods. Later too, of course, it became the universal badge of medicine but it is still a worm wound round a piece of stick—a memento of the earliest surgical operations.

The parasitic worms are very ancient parasites and are not confined to the Mediterranean area. Some are very widely distributed throughout the world. Their importance in the olden days is further emphasized by the fact that until a few years ago practically all the drugs used against them dated back to prehistoric times—not only in the Near East but in the Far East, and even in the Americas.

Worms remained an important factor in human medicine until the discovery of the microscope and the development of the science of bacteriology. The microscopic forms took pride of place among the infections and the macroscopic forms were pushed very much into the background. There they more or less remained until the European nations commenced

the exploitation of the tropics and until Laveran discovered the cause of malaria in Africa and Manson demonstrated the vital rôle played by the mosquito in the transmission of *Filaria sanguinis-hominis*.

Tropical Medicine, with its major emphasis on parasitology, became a reality, and, taking the world as a whole, it was realized that parasitic worms are of an importance comparable with the bacteria, the protozoa, the spirochaetes, the rickettsiae, and the viruses; in fact, in everyday deterioration of health, as causes of chronic debility, they are of more importance to the world than the acute infections caused by the microbes.

Still, however, their importance was largely in the warm countries, where a high temperature, a sufficient moisture, and a relatively poor hygiene among the human population worked in their favour. Modern tropical medicine began about sixty years ago. About thirty years ago attention began to be paid to the Arctic and, rather to everyone's surprise, the worms again began to be seen as important causes of disease. The low temperature and the isolation did not favour the microbes, but the hygiene and the food habits did favour the worms.

My first experience with arctic parasitology occurred some thirty years ago when, as parasitologist to the London Zoological Gardens, I attended the autopsy of a polar bear which had newly arrived from the Canadian arctic and found that it was heavily infected with trichina worms.

The trichina worm has played a most important part in human and veterinary medicine. It is a minute nematode—about one-tenth of an inch long—which lives in the small intestine. There the female worm produces even smaller larvae which are inserted directly into the lacteals of the mucosa and, gaining access to the blood-stream, are carried to all parts of the body. They develop further only if they come into contact with the skeletal muscles. Then they enter the sarcolemma, liquify it, and grow into an immature worm about one-fifteenth of an inch long. They coil up on themselves into a flat spiral, and the fibroblasts of the host form a little fibrous cyst around them. There they remain until eaten by some flesh-eating mammal.

In man this rarely happens and, in due course, the cysts become infiltrated by calcium salts and then—and then only—do they become visible to the naked eye as little white specks, about the size of a pin-head. It was in this form that they were first seen by Paget in London when, as a medical student, he noticed them in the anatomy theatre. In a similar way they were first found in Canada by Osler—one of the founder Fellows of this Society—when he saw them during a dissection in the anatomy theatre at Toronto.

The parasite quickly became important in temperate lands, almost caused the rupture of diplomatic relations between the United States of America and Germany, and, because it was realized that the trichina was conveyed to man in pork, it originated our modern system of meat inspection—even if it is not now looked for in pork in North America.

While the trichina worm is common enough in northern temperate lands, it is absent from the tropics. A consideration of its life history which involves the eating of flesh-eater by flesh-eater suggests, however, that it should be common in the arctic and sub-arctic. And so it has been found to be. Tests by different workers—Canadian, American, and Scandinavian—suggest a very high incidence among the Esquimaux, of whom probably some 30 per cent are infected in the arctic islands and on the shore line.

The parasite has little host specificity; it can mature in any mammal which can be induced to eat raw infective meat. Examination of polar bears showed that trichina was common in them, but the means of infection remained a puzzle until trichina was found to be common in walrus. It has since been found in a great variety of arctic mammals. In herbivorous animals it is rare, although it does occur occasionally. On the other hand, it is far from uncommon in carnivores, especially in those which habitually eat mammalian flesh. It has been recorded, for example, in various seals and small-toothed whales such as the Beluga.

It is more common in mustelids and canines such as Arctic and Red foxes, but the normal cycle is probably a polar bear–walrus one. In the water a walrus can kill and eat a polar bear; on land, the bear kills and eats the walrus. The Esquimau kills and eats both and becomes infected, and the indications are that he often becomes so heavily infected that he dies from the massive invasion of his muscles by the larvae.

In temperate climates, while Black bears are sometimes infected, as also are dogs, cats, and rats, the cycle is mainly a porcine one. By changing the herbivorous habits of the pig to omnivorous ones, civilized man converted a sylvatic infection into a domestic one, and created a new infectious disease.

Man's somewhat insanitary habits in dealing with abattoir refuse and garbage have given the omnivorous rat the opportunity of acquiring infections, but there is no evidence whatever that the rat plays any part in the pig to man or pig to pig cycle. The rat may and probably does play a part in infecting dogs and cats, which in some districts are frequently infected. But again, the rat plays no part in the cycle which involves man—except in cultures where dogs are eaten.

Cooking, of course, kills the parasite and renders it harmless; its protoplasm is coagulated by heat at about 1° F. below the temperature at which pork muscle is coagulated. Slightly lower temperatures will devitalize the parasite so that it cannot develop. The cooking practices of the Esquimaux are often so ineffective that many of the trichina remain alive. Uncooked muscle—even if moderately frozen—is, of course, the most dangerous.

In parenthesis, it should be noted that the infective stages of the parasite occur only in the skeletal muscles. The viscera (including the heart) are not infected and the occasional toxicity of polar bear liver is due to quite different causes.

Another sylvatic infection of arctic regions is the Hydatid cyst which we

have found to be common in both Indians and certain groups of Esquimaux. This cyst is the larval stage of several minute species of tapeworms of the genus *Echinococcus*. The adult worms will develop only in carnivores—such as dogs, cats, foxes, wolves, jackals, and other Canidae. The larval stage will, however, develop in almost any species of mammal and, given time and opportunity, may reach the size of a football. It develops mainly in the liver or lungs. The carnivore becomes infected by devouring the cyst.

The normal cycle, therefore, involves a close relationship between a carnivore and a herbivore. The latter becomes infected by eating herbage contaminated by the excrement of the carnivore containing the minute tapeworm eggs. Accordingly, the parasite is especially common in pastoral countries where sheep, pigs, and horses—and to a much lesser extent cattle —are the intermediate hosts. In pastoral countries man is often an accidental intermediate host, being infected by swallowing the tapeworm eggs either in dust or in food contaminated by carnivore excrement.

The disease in man is especially common in the Mediterranean region, India, Australia, New Zealand, South Africa, and parts of South America where sheep are common. It occurs elsewhere as well, for example, in Great Britain and parts of Europe where foxes rather than dogs may be the common source of infection. In Canada, domestic animals are not infected with hydatid although many years ago we found cysts in caribou in Keewatin, Northwest Territories, and in moose in other parts of the country.

Much to everyone's surprise, it was recently found to be extremely common in man in the Yukon and Northwest Territories where, of course, there are no domestic animals other than dogs. In some northern areas nearly 40 per cent of the Indians reacted positively to skin sensitivity tests. These tests do not necessarily indicate an active infection; they merely show that the subject has been infected and may actually have recovered, because recovery does sometimes take place spontaneously.

Investigations showed that a sylvatic cycle was basic to these infections, wolves being infected with adult tapeworms and deer of various kinds with the cysts. The most commonly infected deer are moose, elk, caribou, and reindeer. Wolves kill the deer, eat the cyst, and in due course deposit eggs on the feeding grounds of the deer.

Ultimately, however, man enters the picture by hunting the deer and throwing their viscera to his dogs, infects them. Six weeks later, the tapeworms mature and commence the production of their microscopic eggs. When not used for hunting the dogs are tied to stakes near the villages, and their faeces, containing these eggs, become dried and are disseminated in dust among the human inhabitants. As the worms in the dog can live for about a year and the eggs can remain viable for about two years, the opportunities for infecting man are good; it is, in fact, surprising that the percentage who have been infected is not even greater than our tests suggest.

It is perhaps worth emphasizing that man is a purely accidental victim of this cycle, that he cannot be infected with the tapeworm stage, that he can handle the cyst in animals with impunity and even eat it, and that the sole source of his infection is eggs derived from faeces of dogs, wolves, or foxes.

In the north country, the cyst, both in deer and in man, occurs mainly in the lungs. Elsewhere it occurs predominantly in the liver. It is a curious fact that hydatid cysts do not occur in farm animals in Canada or the northern United States, although they are found in pigs in the southern States. In St. Lawrence Island, off Alaska, another form occurs which has its adult stage in White foxes and its larval stage in rodents. So far, this species has not been found in Canada.

While the natural human diet in the arctic is mostly of animal origin, not all of it is mammalian flesh. In parts, much of it is fish and that too is a fertile source of parasites. The commonest are tapeworms of the genus *Diphyllobothrium*. All are large forms, sometimes reaching a length of sixty feet, and they occur in dogs, foxes, wolves, and bears, as well as man. There is some reason to believe that bears are the important hosts.

They have a remarkable life cycle. The adult worm, which can live in the small intestine for at least five years and possibly ten, lays eggs at the rate of several million daily. These develop only if they fall into permanent pond or lake water and they pass the earlier part of their developmental cycle in several species of fresh-water plankton. The small crustacea in which this happens are eaten by small fish which, in turn, are eaten by larger fish; in each case the parasite is passed on and some progressive development takes place. Mammals become infected by eating the second fish in an uncooked or under-cooked state.

Elsewhere, this worm has been shown to have very high vitamin B_{12} requirements, and as it lives in the intestine of the host it gets these from the host's food before the host himself does. In northern Europe it is for this reason a cause of pernicious anaemia, but although the tapeworm is quite common in southern Canada there has been no recorded association here between it and any disease. It is a very common worm in the arctic among the Esquimaux, and, possibly, future investigation may demonstrate a causal relationship between it and some of the anaemias reported from them. It is quite possible, however, that in Canada we have a different species from the European form; in fact, we may have several species in our northern country.

In addition to being vectors of tapeworms, fish—both salt-water and fresh-water—are common carriers of trematodes or flukes. While these are relatively non-specific in their adult stages and can occur in man as well as many fish-eating mammals and birds, none is very common in human beings (although there are cases on record). Some are common, however, in dogs and dogs are still of paramount importance in the arctic and sub-arctic.

One of the most important of those infecting dogs is *Metorchis conjunctus*,

a trematode parasite of the bile ducts, which is widely distributed in carnivores over the southern portion of the Canadian Shield. While it has been found in Indians, it is of greater importance in dogs, including sledge dogs, as heavy infections cause a chronic cirrhosis and extreme debility or even death.

The parasite goes through a developmental cycle involving in turn a specific species of fresh-water snail and a specific species of fish—the Common Sucker. Mammals become infected by eating uncooked Suckers. As these fish are very common in our lakes, dogs are frequently fed on them. If the fish are heavily infected, dogs acquire a large number of parasites, develop a clinical picture somewhat like "distemper," and die. If the fish are lightly infected, infections in dogs are light but cumulative, and the picture is one of chronic debility.

In the arctic, dogs have other helminth parasites, one of the most unexpected being a Hookworm (*Uncinaria* or *Dochmoides stenocephala*) which they share with foxes. Unlike the parasites previously discussed, no intermediate host is involved. The hookworm lives in the small intestine, feeding on mucosal cells and causing a steady loss of blood which, in heavy infections, may be considerable and result in a serious or fatal anaemia.

Eggs of the parasites are passed to the exterior in the host's excrement. They hatch and give rise to minute free-living forms which feed on bacteria and similar material. Ultimately, they return to the dog by being swallowed as a contamination of his food or by penetrating his skin and travelling via the bloodstream to the lung, and the trachea to the mouth, and so reach the intestine, where they mature. Closely related or identical forms occur in fur seals, in bears, and in other animals.

There are no human infections with hookworms, however, in the arctic because the species which can infect man are confined to the tropics and subtropics. The reason why only one genus should be widespread in the north is still not clear but is probably attributable to its ability to resist some degree of freezing, a property absent in the other hookworms.

Man in the arctic has one species of worm with a direct life cycle. This is the ubiquitous pinworm (*Enterobius vermicularis*) which has accompanied him in his wanderings since pre-human days and has colonized him in every climatic zone. (The only other parasite which has been so uniformly successful is the common louse; it also occurs in the arctic.)

The pinworm is an inhabitant of man's caecum and appendix. Unlike most other helminths, however, the female does not lay eggs *in situ*, but, when gravid, travels down the large bowel to the exterior, where, dying on the perianal skin, she deposits her eggs all at once in a sticky, irritating fluid. This causes them to adhere to the skin and in a very short time they become infective. The fluid causes itching and the subject, scratching to alleviate the itchiness, removes the eggs on his fingers and in due course transfers them to his mouth. They hatch in the intestine, and the young worm, reaching the caecum, grows to maturity.

The cycle is self-limiting because the female dies after laying her eggs but it is arranged so intimately that reinfection is almost inevitable. In this way, the parasite has been able to remain a parasite of primates, probably since prelemuroid days, and to develop species proper to each species of primate host. Its life cycle is eminently suited to family life, and it seemed to us that Esquimau family life was ideal for its existence.

To prove this, some twenty-five years ago we enlisted the services of the Royal Canadian Mounted Police. Constables going north on service in the *Nascopie* agreed to manicure the finger nails of groups of Esquimaux at each port of call. The trimmings were collected in small vials and returned to the Institute of Parasitology where, after treatment with mild caustic to release the finger-nail detritus, pinworm eggs were recovered from donors of all ages—from babes in arms to the oldest inhabitants.

Of the other great group of parasites—the microscopic Protozoa—we know little of their arctic distribution. The most serious pathogen—*Entamoeba histolytica*—was originally found in St. Petersburg in Russia, and it has been recorded from Alaska. It occurs in southern Canada and probably occurs farther north also, although we have no definite records of its presence there. Our own investigations suggest that the commonest intestinal protozoa in our arctic is the small flagellate—*Giardia lamblia*—which is nearly always non-pathogenic. What may be the same species is also common in dogs.

Research on arctic parasitology has really just begun. Very little, for example, is yet known of the parasites of small rodents. Beavers have been surveyed and found to contain several important species of helminths, whose connection with disease is unknown. In general, parasites of wild animals are not serious pathogens to their natural hosts. It is only when man interferes with them or they get opportunities to infect new hosts, such as man or domestic animals, that they become important causes of disease.

Two interesting examples of these are *Capillaria hepatica* and *Fascioloides magna*.

Capillaria hepatica is a small nematode which lives quite commonly in the liver of rodents in Canada. It lays its eggs there and causes a considerable destruction of tissue. Only with the death of the host, however, do the eggs escape, either as the result of decomposition after natural death or as the result of the digestive processes of another animal which has eaten the infected liver. Once free of the host tissue the eggs must remain outside the body for a developmental period of several weeks before becoming infective to a second host. Infection probably involves swallowing the egg as a contaminant of food.

The parasite, while primarily a rodent one, can also occur in man and there are a number of authenticated cases in the United States. It has not been looked for in our northland—there is no means of diagnosis during life except by biopsy and it must be searched for on autopsy—but there is every probability that it does occur. Its frequence in rodents, the feeding habits of dogs, and the methods of restraining dogs in Indian villages, are

certainly conducive to its occurrence in man. Its symptomatology is vague but, like all somatic metazoan parasites, it causes a fairly high eosinophilia.

Fascioloides is not really an arctic parasite but it is so close to being one, that it is not inappropriate to mention it here. It is a rather large trematode indigenous to American deer but which can also infect cattle and sheep. Its life cycle involves a fresh-water snail and an infective stage on grass. In deer it lives partly, but only partly, encysted in the liver, and its eggs can escape with the bile and so reach the exterior. In cattle the host reaction is so pronounced, and the parasite so completely enveloped in dense fibrous tissue, that its eggs cannot escape; cattle cannot, therefore, infect other cattle, although they themselves can develop these cysts in the liver. In sheep, on the other hand, the host reaction is so poor that the parasite can wander through the liver and cause so pronounced a disturbance that the sheep may die. The sheep also cannot infect other animals because the host dies before the parasite reaches sexual maturity. Deer do not suffer from the presence of the parasite and cattle or sheep can become infected only when grazing on pastures previously grazed by infected deer.

It is very important to realize that there may be a vast difference between infection with parasites and parasitic disease. Helminths have always been associated with disease in the human mind—an association probably traceable to the great antiquity of these parasites, perhaps also to the fact that they can be seen. Actually, most helminthic infections have little clinical significance.

Disease when it occurs, is usually due to numbers of infecting forms. There are exceptions to this rule as, for example, in the case of the hydatid cyst which, because of its size, may produce impressive effects. Sometimes, also, there are accidents as when a cyst is ruptured, or when an Ascaris invades the bile duct.

Normally, however, disease is due to numbers. A single female worm will produce during her life about five hundred embryos. Even if all of these invade the skeletal muscles—and this is highly improbable—the clinical effects produced by a single adult worm will be unnoticed. There is no possibility of these highly organized parasites multiplying within the host as, for example, can the bacteria and viruses. Their young must enter a new host before they can mature and the cycle can be repeated. In other words, one worm in the host must remain one worm.

If disease is due to numbers, then it follows that when clinical disease does occur a considerable number of immature stages must have been able to enter the host and become established. Disease, therefore, is dependent *on exposure*. This exposure may and usually does take place over a period of time, although sometimes—as is the case with the trichina—a large number of infective larvae may be eaten at a single meal and clinical disease result. Heavy infections with most worms, however, require a considerable period of association with a source of infection. Moreover, these parasites require a definite developmental cycle outside of the body of the definite host under quite specific environmental conditions.

As exposure to infection must vary from individual to individual, symptoms must also vary from none at all to severe effects—a circumstance which makes clinical diagnosis difficult and more than ever dependent on laboratory examination, and this, in the arctic even with a highly organized medical service, is particularly difficult to obtain.

Fortunately, prevention can be practised with a reasonable prospect of success. Hydatid cyst depends on contamination with the excrement of infected dogs, trichinosis on eating uncooked meat, and so infection can be avoided. Pinworms are more difficult to get rid of—even in southern Canada with our superior hygiene nearly half the population is infected—but, fortunately, their pathogenicity is slight. Moreover, treatment is available for these, as it is for most of the other intestinal infections. There is, however, no treatment except surgery for the hydatid cyst and there is, as yet, no treatment at all for trichinosis, which remains the most serious, and possibly the most common, of the arctic diseases.

With the enormous and increasing development of the northlands there is an obvious need for continuous and intensified research into the relationship between man and beast and the methods of the spread of infections from one to another, as well as the steps which can be taken to prevent this spread. From the medical and veterinary points of view, much remains to be done not only on methods of diagnosis and treatment and in the application of the results of investigation during the past twenty-five years, but on exploratory work into the parasitic fauna of all arctic animals.

The arctic is a surprising place with its long days and its long nights, its short summer and its long cold winter, its dependence on wild animals for human food and on dogs for hunting and transport. Perhaps the most surprising thing, however, is the importance of animal parasites in the health of both man and dog.

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SECTION FIVE

PRESIDENTIAL ADDRESS

Research in the Biosciences: A Mid-Century Perspective

W. H. COOK, F.R.S.C.

Introduction

IN these days of rapid change it is presumptuous to attempt a broad survey of biological science in half an hour. It would be impossible even to sketch the recent advances in my own field of biochemistry. To narrow the field, and still retain something of general interest, my remarks will deal with two aspects of Canadian university research. The first is concerned with the support of university research and graduate training; the second with the training of research personnel to meet modern trends towards biosciences concerned with cellular, subcellular, and molecular levels. It may seem even more presumptuous that anyone outside a university should venture an opinion on academic matters, but the shortage of research personnel and the background training of those that are available concern every employer.

On an anniversary occasion such as this the historical aspects of our research effort come to mind. Fortunately, the last anniversary meeting dealt admirably and in detail with the progress during the first fifty years of this Society, and you are well acquainted with the conditions, progress, and problems of the past twenty-five years. Canadian research as a whole has passed through its childhood and is now, depending on the general field of science one chooses to consider, in its adolescence or early maturity.

Childhood

The period of growth or childhood extends from the early beginnings to about 1939, the year this Section had its twenty-first birthday. For in spite of Canada's stature in certain fields, she was still a small country scientifically at the beginning of the last war. In World War I only a few Canadians had served in a scientific capacity and these mostly in institutions abroad.

Many noteworthy contributions were made by Canadian biologists during this early period. In reporting some Canadian scientific achievements in 1885, Sir William Dawson said he could not report progress in the physical sciences to equal that of the natural sciences. The extraction of insulin and the breeding of early maturing, rust-resisting wheats are notable examples of contributions the Fellows of this Section made to human health and well-being.

A century ago Canada was dependent, in large part, on personnel born and trained abroad to staff our few universities and scientific posts. Still later, many of our students had to go abroad for advanced training since few Canadian universities gave graduate work in the sciences. While a reasonable exchange of staff and students is essential for healthy research, excessive dependence on outside resources indicates immaturity.

Adolescence

The rapid change and growth of Canadian science since 1939 are typical of adolescence. In World War II many Canadian scientists served at home. We had grown considerably but we still lacked the maturity to be assigned major scientific problems during the early period of the war. Major conflicts are usually least productive in the creative sense, but the last war brought a great appreciation of scientific research, funds for the growth of that research, and many changes in the minds of men. Inspired as tools of war, radar, jet aircraft, and atomic bombs became synonymous with scientific progress in the public mind and left the significance of such contributions as antibiotics to be appreciated by those to whom they restored health. Under this wartime stimulus Canadian physical science reached a reasonable maturity with respect to its training and research facilities, but Canadian biological science is still immature.

The postwar period has brought, not only a stabilization of the peak scientific effort attained during the war, but a more balanced growth in all branches of science. The greatest change is that Canadian industry, stimulated by technological development and a buoyant economy, has come to appreciate the value of research. Industry has therefore joined the universities and government agencies as an employer of scientific and research personnel. During recent years the universities have been unable to meet the demand for graduates, whereas in earlier years they had a surplus for export. The quantitative shortage of research personnel may also have brought a hidden qualitative shortage that may eventually be more serious.

Maturation

The rate of maturation attained by Canadian research in the future will depend on the leadership given by Canadian universities. All research institutions depend on the universities to provide qualified personnel. Again, they are the only institutions which can have their research oriented solely as a contribution to knowledge, whereas most non-university research must have some plan or purpose and to that extent the initiative or originality of the research worker may be curbed. Finally, as Canadian industry devotes only about 4 per cent (1) of its own research expenditures to biological science, the universities are themselves responsible for a major segment of Canadian biological research.

While a lack of students is partly responsible for the present shortage of research personnel, the persistent shortage of funds has been the main factor

limiting the development of university research and graduate training. During recent years both the taxpayer and industry have gained some appreciation of the problem facing our universities, and the present favourable atmosphere is bound to bring some improvement. But the taxpayer thinks of the university as a place to educate his family, and industry thinks of it as a place to get trained staff. These are worthy motives but they do not ensure that either biological science or university research funds will increase in proportion to the over-all enrolment or budget. In fact, the glamour and employment opportunities in the physical sciences are likely to decrease the proportion of the student population entering biological science, and if the expected increments in registration precede the increments in staff and facilities, there may be little additional funds or time to devote to research.

Sir William Dawson's statement, quoted earlier, suggests that the ratio of biological to physical research scientists may have been nearly 1:1 when this Society was formed. The ratio in Canada today is probably 1:3 or 4, and with increasing industrialization the trend will be towards the present United States position of one biological research worker to nine physical scientists. Biological science and physical science are partners, not rivals, except perhaps in competing for the better students, but the difference in scale creates additional difficulties for the departments that train biologists.

Financing University Research and Training Centres

The geography and population of Canada require that the relatively small number of biological teachers and graduate students be spread over a considerable number of universities. Biology departments in general are therefore small, and the effective research effort may fall on one or two individuals, even in institutions granting advanced degrees. The quality of the individual staff members may offset the numerical deficiency but is hardly adequate to ensure stability. The loss of a key individual may mean a successor with different research interests and aptitudes. Stability is important in establishing the reputation of a department among students and grant-giving foundations. Graduate training in biological science in a number of Canadian universities has suffered as the result of the small number of staff members available.

These views are apparently shared by Canadian students undertaking graduate work in the biosciences during recent years. The number that go abroad for advanced training is essentially the same as the number trained in Canadian universities (2). Lest this be attributed to more generous scholarships, employment opportunities, or salaries, comparson with the physical sciences, where similar conditions prevail, shows that over two-thirds of a much larger number secure their graduate training at home.

Effective strengthening of biological research in the universities will require the addition of experienced research personnel to supplement the existing staff and allow proportionately more time for research and training

of graduate students. Obviously, neither the available funds nor the available graduate students would justify such an augmented staff for every biology department in every university. The essential minimum is one adequate Canadian training centre in each biological specialty in which we are now dependent on outside resources.

It would be ideal if the university could provide the necessary research staff from its own budget. This is not likely to occur in the next decade with the growing need for buildings, other facilities, and teaching staff. Fortunately, part of the funds for research now comes from sources other than the general university budget. These include: graduate scholarships, post-doctorate fellowships, capital grants for research equipment, assisted research grants, and research contracts. Most of these are small grants that can be used to finance work conceived by the professor. The research contract differs from the other forms of financial aid by placing more emphasis on the problem, sometimes defining it specifically. Contractual arrangements that affect the freedom of research are undesirable as they reduce university research to the type performed by government agencies and industry.

Research contracts available to the biological sciences are generally small. All the outside support for university research can therefore be described as an "individual" or "small-grant" formula. These grants are valuable and could reasonably be increased in number, but they do not meet the requirements of the biological sciences.

If we are to add the senior staff and facilities to strengthen research in biological departments we need a "departmental" or "large-grant" formula, with reasonable assurance of continuity, to supplement the "individual" formula. Two years ago I suggested that industry might be prepared to finance a few research professorships. Some exploratory canvasses indicate that industry is sincerely interested in scholarships to train personnel and possibly in research contracts to solve general or specific problems, but it has shown little interest in strengthening graduate schools. Any support industry provides will likely be in the physical sciences, and the biological sciences can expect little or nothing.

Government departments, federal and provincial, would seem to be the best source of departmental grants. Governments are generally sympathetic to the universities' problems; many of their departments are interested in obtaining trained biologists and in biological research, and they have contributed most of the funds for the "small-grant" formula, often as research contracts. When a government department lacks staff this financial aid advances the solution of a practical problem, but it does little to solve the basic need for trained personnel. The "departmental" or "large-grant" formula should be attractive to government departments, and the reputation of the university department and the interests of the donor would determine where the grants were made. University professors who act in an advisory capacity to government would seem to be the best people to explore this possibility.

The differences between grant-giving agencies, whether provincial or federal, should be noted. In general, research councils have a broad field of interest in research, whether biological, chemical, or physical, and a "small-grant" formula is usually the only one possible with the available funds. On the other hand, those departments concerned with agriculture, fisheries, forestry, wildlife, and health have specialized research interests and responsibilities and are likely to benefit most from the "large-grant" formula.

It is visualized that this jointly supported research unit would be under university control and would enjoy full academic freedom. The university would presumably have to give some assurance that the donors' funds would be devoted to graduate training and research. In the physical sciences, Atomic Energy of Canada and the Defence Research Board use comparable formulae to provide properly trained personnel for their specialized research establishments. Research units of a comparable type have been established in British universities by the Medical and Agricultural Research Councils. The Institute of Parasitology at Macdonald College is the only Canadian example of the proposed arrangement known to me in the biological field.

Canadian training of our own research personnel in the biological sciences is an essential step towards scientific maturity. Building up research centres in our universities is not enough; we also need Arctic and marine biological stations to meet the needs of the several field biologies. This could be done as a joint effort by several universities, and these subjects are of sufficient interest to several government departments to justify financial aid.

While there is much to be done in these fields in Canada, a mature science must have a more international outlook. Exploratory trips are expensive but this has been solved in other branches of science by such devices as the International Geophysical Year. Similarly, could not an International Biological Year be organized to permit biologists to participate in a broad plan of organized study that is adequately financed? Canadian scientists have participated in such international activities as individuals. When we can organize such studies and invite others to assist, we shall have attained maturity. Will it be this century or next?

Training Future Bioscientists

Turning to more academic matters, if one serves on a mid-century selection board responsible for research appointments, one notices immediately the general shortage of personnel. Further study shows that the biological sciences suffer a large, invisible loss, not of those who enter college and do not graduate, but of those who graduate at the Bachelor's level and are lost to the profession. While this is generally true, a recent British survey (3) provides the most complete figures.

This survey covers some 3,400 graduates in biology at the Bachelor's level from British universities over the five-year period 1950–4. Somewhat over a third of these graduates obtained teaching or research posts in universities,

government agencies, or industry; about a third became school teachers; and the remainder, something less than a third, were not employed as biologists and therefore were lost to the profession.

The loss of women graduates through marriage is a factor, but the main reason given for these losses is that a greater proportion of the students of mediocre scientific ability take biology because it is considered easier. Since biological appointments are mainly to teaching and research positions, people lacking the requisite abilities cannot find employment within their profession, as can the less qualified chemist, who can be employed in industrial production. In fact, the British report states: "This supplies a further reason for the biologist receiving training in chemistry and physics: qualifications in these subjects may enable him to obtain employment. . . ."

In Canada we also suffer visible losses in the form of graduate students who go to the United States for advanced training, accept positions there, and do not return. The available evidence indicates that this loss of qualified personnel could be sharply reduced if our biological research centres in degree-granting institutions were strengthened so that those interested in almost any field or specialty could take their training in Canada.

The next problem confronting our mid-century selection board is the qualifications of the applicants for the available positions. In the prewar era one candidate could be selected for both his inherent ability and his background training from the several applicants for each post, and a wasteful surplus was left unemployed. Now, with a scarcity of applicants, the task is to fill as many openings as possible from the available candidates. Graduation may indicate the required ability, but in the biosciences the training of about half the applicants is of doubtful suitability for the available positions. While it is not the task of a university to train a man for a specific job, general training in the biological sciences might be advantageously modified.

The basic fact is that about half the students now taking graduate work in biology in Canadian universities are specializing in fields of biology concerned with the cellular or sub-cellular levels, that is, cytology, microbiology, biochemistry, etc. These biosciences are experimental rather than descriptive, and since the trend is in this direction the employment opportunities in these fields are already large and are likely to become even larger. As Dr. Paul Weiss (4) has said, "If education is to serve the needs for which it was designed, it must be alert to the changes in the needs and adapt itself to them."

Evolutionary changes have certainly taken place in undergraduate teaching but in general these changes have not kept pace with the changes that find only half the graduates taking the classical biologies, which still dominate the teaching. Our quantitative record for training general microbiologists in Canada is appallingly deficient, although the quality has been good. Could this be because the student had only one, or at most two, microbiology courses when he graduated? Similarly, the potential biochemist has the option, by necessity or choice, of meeting the requirements of his

biology course, at the expense of an adequate knowledge of chemistry and physics, or of transferring to physical science, thus ensuring that his knowledge of biology will stop at the molecular level. Both alternatives produce a lopsided result and a net loss to biological science.

Obviously both the observational and descriptive systematist and the experimental biochemist or bacterial cytologist are *equally* important to biology. Could not the scientific needs of both be met by a first course that would deal with the structure, physiology, and genetics of the living cell? Individual cells, even those of lower forms, show the attributes of life; all share a protoplasmic structure and many physiological processes, and are governed by the same laws of inheritance. This knowledge is basic to any biology, and the laboratory work should give equal emphasis to descriptive and experimental phases.

In later years, and within the confines of a reasonable biological background, the students could obtain adequate basic training for graduate work in their field of choice. In particular, the biochemist and biophysicist would spend less time on the biologies that may be of interest but not essential to their training, and would use the time gained to take additional courses in the physical sciences. This may be considered narrow specialization but it need not be, and since taxonomists or ecologists know little about the Krebs cycle, it seems no more important for the biochemist to be able to recognize the characters that distinguish different *Gramineae*. Both are fundamental links in biological knowledge, but the essentiality of these detailed facts depends on the field of interest.

If biological teaching started with the living cell it would be comparable to the approach used in the physical sciences. Chemistry is taught by showing how atoms are built into simple and complex molecules with different properties. A large section of physics is now concerned with the distinguishable entities present in the once indivisible atom. Starting with the living cell, we can build more complex structures than the chemist ever thought of, and with cheaper equipment we can distinguish more structures within it than the physicist is likely to find in any atom. Such an approach would put us in a much better competitive position for some of the students who now succumb to the glamour of the physical sciences.

Since students vary in their aptitudes some may be observers, others experimentalists, and still others theoreticians, but few combine the abilities of all three. Under present methods of instruction, those with a flair for the observational and descriptive, or with little aptitude for theory and experiment, gravitate toward the biological sciences. This difference in aptitude may partly explain the general impression that biology is easier than the other sciences. Some of these students, who graduate but are lost to the profession, might be eliminated at an earlier stage if the introductory courses in biology were altered to demand more thought and less memory. At present biology tends to lose the laboratory experimentalist, who gravitates to the physical sciences at a time when he is badly needed in the newer experimental biologies.

In the whole of science there is no more dismal gap than that which exists between the biological and physical sciences—or more specifically, between the cellular and molecular level. From measurements on nucleic acids the physical scientist has given us a model of this complex molecule, but the relation of this to the gene, which the biologist juggles to produce new varieties, is as obscure as ever. Problems from cancer to photosynthesis are being studied by chemists who frequently have little knowledge of the dynamics of unstable living systems and entities that can reproduce themselves. Conversely, biologists working on these problems speculate about physical and chemical properties that are already known.

Rapid progress is being made at present on the accumulation of facts in this twilight zone between the living and non-living worlds. This can be done by associating biological and physical scientists on a research team. Indeed, the requisite facts for a major advance in our understanding of some important biological processes may be available now or in the near future. But a creative synthesis of these facts is not likely to be made by a team of builders where the thought of each member is confined to his own trade. We have all too few architects, and their appearance seems to be a matter of unpredictable mutation or spontaneous generation. Perhaps the mutation rate could be increased if we had more graduates with a thorough knowledge of both the cellular and the molecular states.

Canada's growth and prosperity will force many changes in our university education and research in the last half of this century. An increased proportion of our students is likely to attend junior colleges, and these will not be research institutions. This isolation from research activity will necessitate some alteration in undergraduate teaching if we are to create an interest in a sufficient number of students to meet our future requirements in the experimental biologies.

Research in the physical sciences can reasonably expect increasing support from industry, but research funds for the life sciences will continue to come almost entirely from the taxpayer. Research in the physical sciences, therefore, will have more financial resources and flexibility than that in the biological sciences. The needs of the life sciences will require a new formula for making grants as well as more adequate funds. Leadership in devising this new formula must come from the university biologists, and action is needed now.

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